Exploitation of Thermal Signals in Tidal Flat Environments

Jim Thomson
Applied Physics Lab, University of Washington
1013 NE 40th St, Seattle, WA 98105
Phone: (206) 616-0858 Fax: (206) 543-6785 Email: jthomson@apl.washington.edu

Chris Chickadel
Applied Physics Lab, University of Washington
1013 NE 40th St, Seattle, WA 98105
Phone: (206) 221-7673 Fax: (206) 543-6785 Email: chickadel@apl.washington.edu

Award Numbers: N000140710768, N000140710682

LONG-TERM GOALS

The overall goal is to identify and understand the physical processes that shape and change coastal environments. Emphasis is on the application of remotely sensed signals that can be compared with in situ observations and assimilated within predictive models. In tidal flat environments, the major goals are to detect geotechnical properties (e.g., sediment strength), morphologic features (e.g., channels), and related hydrodynamic events (e.g., plumes).

OBJECTIVES

The primary objective of these joint efforts is to develop thermal methods for improved monitoring and prediction of tidal flat environments. Specific objectives are to:

- Participate in planning efforts for the Tidal Flats DRI, including site evaluation.

- Develop an integrated system for in situ and remote (infrared) measurements of thermal signals in the field.

- Test and apply the Lovell [1985] hypothesis for the porosity of sediment as a function of thermal conductivity.

- Explore inverse methods to optimize the assimilation of remote and in situ observations.

APPROACH

The technical approach is to conduct laboratory and field experiments using simultaneous remote and in situ observations of thermal signals in tidal flat environments (Figure 1). The experiments are designed to study geotechnical and hydrodynamic aspects of tidal flats (Thomson, N000140710768). In addition, both investigators are participating within the planning phase of the Tidal Flats DRI (Thomson & Chickadel, N000140710682), in preparation for a series of large collaborative field experiments. The planning phase includes meetings and field trips to characterize potential sites, as well as logistical concerns.

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**
4. TITLE AND SUBTITLE **Exploitation of Thermal Signals in Tidal Flat Environments**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Lab,1013 NE 40th St,Seattle,WA,98105**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

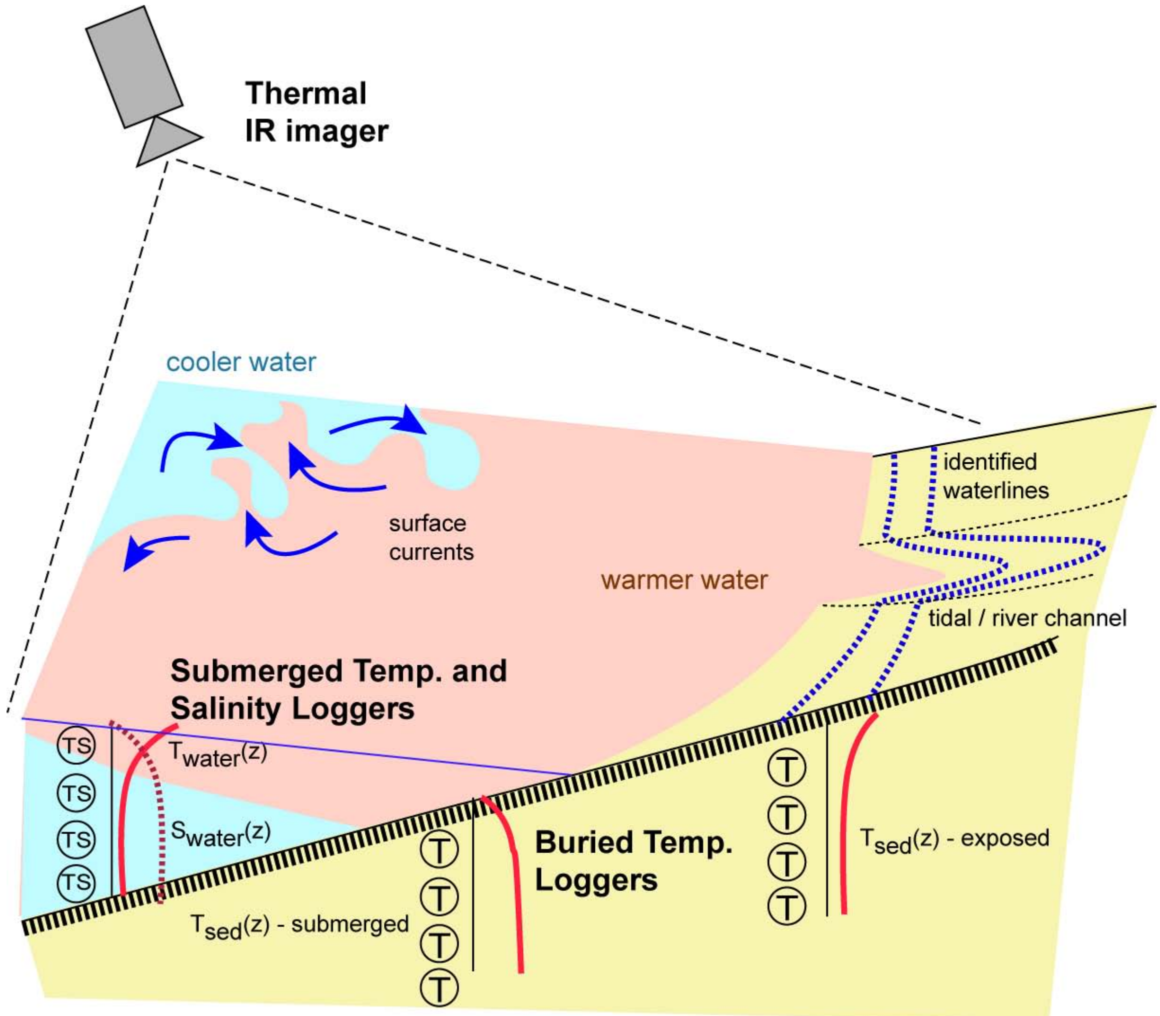

Figure 1. Schematic diagram showing infrared and in situ measurements of thermal signals in a tidal flat environment. The infrared measurements of surface temperature are made from an elevated platform, and the in situ measurements of interior (both water and sediment) temperature are made from anchored platforms.

The laboratory and field data will be used to test Lovell's [1985] empirical formula for the fractional porosity n (i.e., the water content) of saturated sediments as a function of thermal conductivity k, where

$$k = k_s^{(1-n)} k_f^{(n)},$$

and k_s, k_f refer to the thermal conductivities of the solid and fluid, respectively. Assuming a 1D heat balance, the temperature T at the surface of the sediment (measured using infrared imagery, see Figure 1) diffuses downward in a vertical z profile (measured using buried loggers) at a time t rate governed by

$$d^2T/dz^2 = (c\rho/k)\, dT/dt,$$

where k is the thermal conductivity of interest, c is the specific heat, and ρ is the density [*Subramaniam and Frisk*, 1992; *Jackson and Richardson*, 2002]. Sediment porosity n will be estimated by finding the best-fit *k* at each location in the imagery and then will be compared with sediment samples collected by C. Nittrouer & A. Ogston (University of Washington).

The field data also will be used to quantify surface fluid velocities (using imagery [*Holland et al.*, 2001]) and estimate volume transport (using in situ data [*Wunch*, 1996]). These hydrodynamic quantities will be used to evaluate correlations with bathymetric features, such as channels, and will be compared with velocity measurements by S. Elgar & B. Raubenheimer (Woods Hole Oceanographic Institution).

WORK COMPLETED

During this first year, investigators have attended DRI planning meetings in Hawaii and South Korea, scouted field sites Washington State, begun development of new methods, and collected preliminary data.

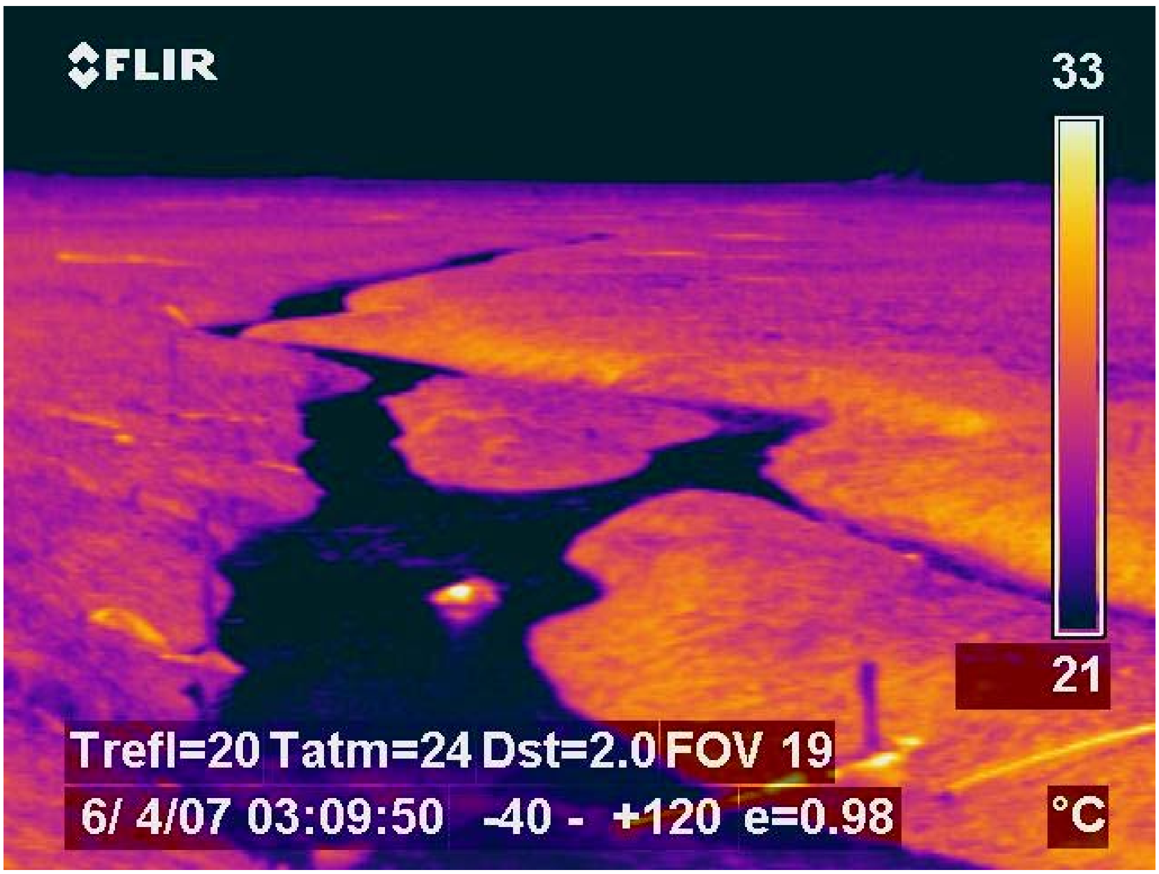

Figure 2. Infrared image of a tidal flat (warm signal) and channel (cold signal) at Marisan Beach, South Korea. Such thermal signals are common on tidal flats.

The preliminary data, collected by Thomson, include infrared images from Korean sites (Figure 2), and sediment temperature profiles from Washington State sites (Figure 3). In addition, laboratory tests of sediment temperature loggers have been completed and a new infrared imaging system is under development. The laboratory tests validate the preliminary field measurements (Figure 3) and indicate that the rms error associated with the logging system, including the effects of sediment anchors, is less than 0.1 °C. Processing of the field measurements is ongoing, including the development of new software and methods to obtain best-fit conductivity *k* values from the data.

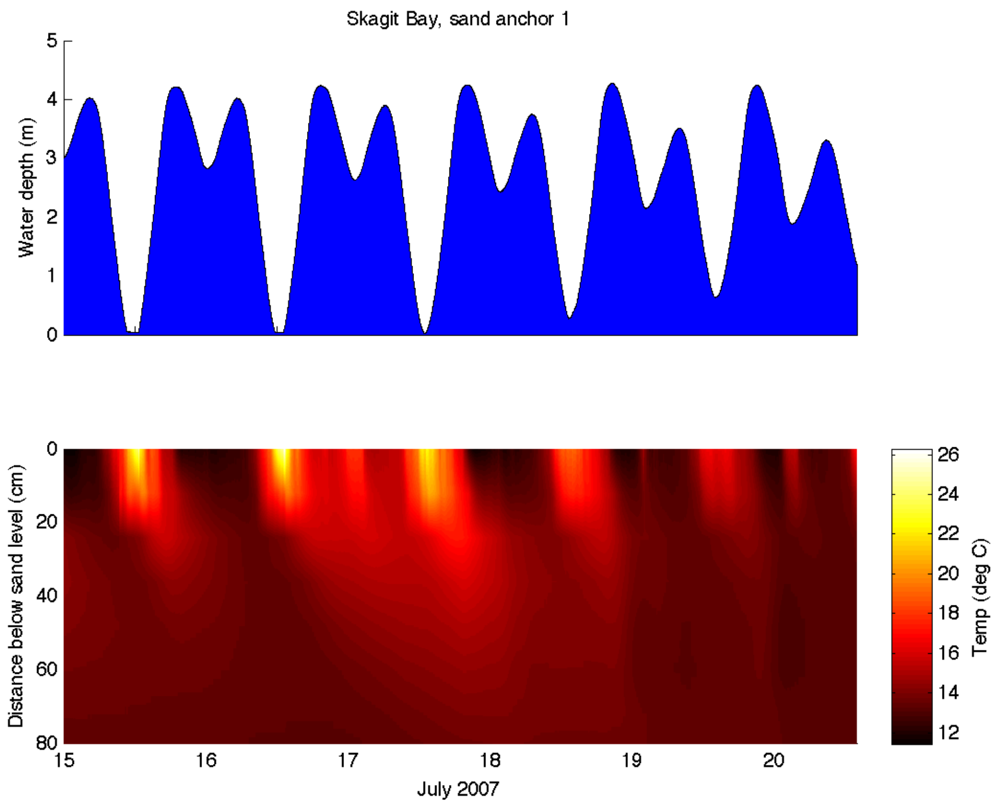

Figure 3. Tide (upper panel) and sediment temperature profiles (lower panel) recorded near English Boom Park, Skagit Bay, WA. At low tide the upper layer of sediment is heated by solar radiation, and this heat is conducted downwards over time.

Other new methods, under development by Chickadel, include estimation of inter-tidal bathymetry by determining the waterline within images at each stage of the tide and interpolating to form a Digital Elevation Model (DEM). The DEM can be calculated at regular intervals to track inter-tidal morphology [Ryu et al., 2002]. Figure 4 shows an example using infrared images from the COHSTREX experiment (July 2006), as well as a comparison with survey data (January 2007). Infrared sensing is ideal for this method estimating bathymetry, because the waterline can be extracted day and night and because infrared is less prone to errors from pooled/stranded water left on the tidal flats.

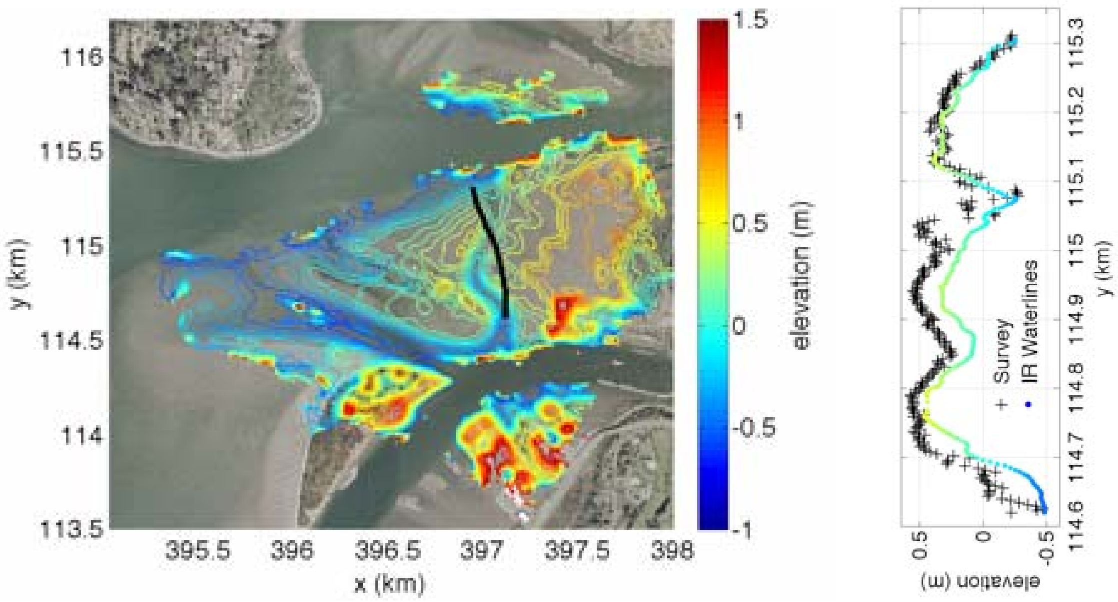

Figure 4. Inter-tidal elevation map (left panel) and transect (right panel) calculated by extracting waterlines in sequential infrared images. The transect (colors) is in agreement with survey data (pluses) along the black path (y = 114.6 to115.3 Km).

RESULTS

Results during this first year are primarily related to the evaluation of domestic field sites for the Tidal Flats DRI. Figure 5 shows satellite images of the Skagit Bay and Willapa Bay, both of which have been documented thorough field trips and collection of existing resources (i.e., data, publications, personal communications). This information has been prepared for distribution the DRI community at large, in support of a draft science planning and pilot experiments. Additional results include the confirmation of significant thermal signals (eg, Figures 2 & 3) at each field site.

The Skagit Bay site is a predominately sandy tidal flat with active braided channels, although pockets of mud suggest that fine particles (i.e., mud and silt) are present in the system and being transported through the flats to deeper regions [*McBride et al.*, 2006]. The river input is large, with an average peak flow of 71,310 cfs (north and south forks combined, http://waterdata.usgs.gov/nwis/uv?12200500). At the northern end of the bay, there is a region of relic (eroding) mud, possibly owing to the construction of a breakwater. Along the southern perimeter of the bay, an active depositional band of mud exists within a few hundred meters of the shoreline. The spring tidal range is 4 m (http://www.cfdnet.com:8080/locations/3237.html).

The Willapa Bay site is predominantly muddy tidal flat with stable meandering channels, although a few sandy areas are present at the seaward edges [*Ferraro and Cole*, 2007]. River input is small, with an average annual peak flow of 14,680 cfs (Naselle and Willapa Rivers combined, http://waterdata.usgs.gov/nwis/uv?12200500, http://waterdata.usgs.gov/nwis/uv?12013500). The southern portion of the bay is extremely muddy and difficult to traverse. The spring tidal range is 4 m (http://www.cfdnet.com:8080/locations/4603.html).

Figure 5. Tidal Flats DRI domestic field sites. The Skagit Bay (left image) is an approximately 15 x 15 km site centered at 48°18'52.43"N 122°27'33.97"W. The Willapa Bay (right image) is an approximately 10 x 10 km site centered at 46°25'14.67"N 123°57'34.46"W.

IMPACT/APPLICATIONS

Improving techniques to remotely quantify tidal flat properties will allow for real time monitoring and safe operation in these environments. In particular, remote porosity estimation and channel detection will improve navigation for amphibious landings. In addition, the development of techniques to assimilate remote and in situ measurements will facilitate the testing of predictive models.

RELATED PROJECTS

An ongoing DURIP (PI: Andrew Jessup) to develop a "helikite" aerial platform for scientific imaging will improve the spatial coverage and duration of planned field experiments.

An ongoing MURI (Coherent Structures in Rivers and Estuaries Experiment, PI: Andrew Jessup) has provided infrared image data for proof of concept applications in the remote sensing of tidal flats (www.cohstrex.apl.washington.edu).

This effort is a contribution to the Tidal Flats DRI (www.tidalflats.org).

REFERENCES

Ferraro, S.P. and F.A. Cole, 2007, Bethic macrofauna-habitat associations in Willapa Bay, WA, USA, *Estuarine, Coastal, and Shelf Science*, 71.

Holland, K.T, J. A. Puleo, and T. N. Kooney, 2001, Quantification of swash flows using video-based particle image velocimetry, *Coast. Eng*., 44.

Jackson, D.R., and M.D. Richardson, 2002, Seasonal temperature gradients within a sandy seafloor: implications for acoustic propagation and scattering, *IEEE Ocean Eng*., 26.

Lovell, M.A., 1985, Thermal Conductivity and Permeability Assessment by Electrical Resistivity Measurements in Marine Sediments, *Mar. Geotech*., 6(2).

McBride, A., K. Wolf, and E.M. Beamer, 2006, Skagit Bay Nearshore Habitat Mapping.

Ryu, J.-H., J.-S.Won, and K. D. Min, 2002, Waterline extraction from Landsat TM data in a tidal flat: A case study in Gomso Bay, Korea, *Rem. Sens. Env*., 83.

Subramaniam, D. and G. V. Frisk, 1992, Seasonal variations of the sediment compressional wave-speed profile in the Gulf of Mexico, *J. Accoust. Soc. Am*., 91.

Wunsch, C. (1996), *The Ocean Circulation Inverse Problem,* Cambridge University Press.

HONORS/AWARDS/PRIZES

ONR Young Investigator Program (N000140710768): Jim Thomson, Applied Physics Lab, University of Washington.